PRESSURIZED STRUCTURE TECHNOLOGY FOR UAVS

H. Edge*, M. Nixon, A. Janas, W. Ross, J. Collins
U.S. Army Research Laboratory
Attn: AMSRD-ARL-VT-UV
Aberdeen Proving Ground, MD 21005

ABSTRACT

There is a critical need to improve the performance and utility of unmanned aerial vehicles (UAVs). Several areas of UAV performance need to be improved for the next generation of UAVS to be used successfully in expanded future combat roles. For example current time aloft is only on the order of an hour or two for electric-powered UAVs. The current generation of UAVs lacks vertical takeoff and landing (VTOL) capability and precision slow-speed maneuverability required for urban navigation and targeting. In addition, the UAVs are not capable of stealth, and are easily spotted and/or heard. These deficiencies are related mostly to the airframe and method of propulsion. Most fielded UAVs are currently based on fixed-wing or rotor-craft airframes and thus are constrained to their flight characteristics. UAV propulsion using ducted fans may also be fielded. In general, these vehicles require the motors, electrical or internal combustion to be running at high speed to keep the UAV aloft. This requires a substantial amount of energy and generates noise at excessive levels. One way to address the deficiencies of the UAVs just listed is to employ lighter-than-air or pressurized structure-based (PSB) technology. Basically, the UAV will be built such that a considerable percentage of its weight is supported by or constructed from inflatable structures containing air or helium. PSB technology will reduce the amount of energy required to keep the UAV aloft thus allowing the use of smaller, slower, and quieter motors. An airframe near neutral buoyancy will allow much slower flight speeds and increased maneuverability while expending little power. PSB airframes used in conjunction with technologies such as solar cells may be able to stay aloft for extended periods of time.

1. INTRODUCTION

The objective of this research is to explore, develop, and demonstrate the feasibility of PSB technology for UAV aircraft. PSB technology will be used to address the shortcomings experienced with the current generation of UAVs and add capabilities to UAVs which will allow expanded roles in missions for the Armed Forces. With proper vehicle design, PSB technology can be used to greatly increase flight time, and/or payload. It can offer increased portability of UAVs by allowing a substantial amount of the UAV fuselage and wings to be inflated. PSB technology can offer stealth by reducing UAV weight and allowing smaller quieter energy-efficient propulsion systems. With substantial investments in research and design, it may be possible to advance PSB technology to the point where aircraft may approach neutral buoyancy through the use of helium. This capability would enhance the previously listed flight characteristics. Maneuverability would be increased for added effectiveness in urban environments, and flight endurance and noise levels will be improved.

In order to realize the benefits of pressurized structures, new materials, technologies, and techniques will need to be employed. For example, the UAV may be made lighter and partially buoyant by PSB technology, but without corresponding changes and/or improvements in the propulsion system to take advantage of the airframe, it will still produce too much noise to allow the vehicle to be used for missions requiring stealth. Thus, this research includes investigations into all phases of aircraft design, materials, propulsion, control algorithms, etc. To focus the design effort, the UAV airframe specifications will be tailored to perform a long duration reconnaissance mission. There are four basic research areas that must be addressed in PSB UAVs in order for them to perform critical tasks for the Army in the future.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2008**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Pressurized Structure Technology For UAVS**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Research Laboratory Attn: AMSRD-ARL-VT-UV Aberdeen Proving Ground, MD 21005**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002187. Proceedings of the Army Science Conference (26th) Held in Orlando, Florida on 1-4 December 2008, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1.1 Pressurized Structure Component Technologies

First, materials and new assembly processes must be employed to achieve buoyancy for an extended period of time. It is most likely that helium containment will be used to provide buoyancy. Thus, an effective structure must be designed to contain helium for extended periods of time, while providing a rigid low-drag aerodynamic shell with enough lift to keep the aircraft aloft. Helium retention and buoyancy control will be major hurdles; however, advancements in long duration balloon design, fabric materials, and high-pressure compressed air structures can be adapted for this research to make it feasible (Nickol et al. 2007).

1.2 UAV Design

Second, a viable UAV that is capable of performing missions of interest to the Army must be designed. The final design should be focused toward the goal of achieving long-duration flights which is a capability that is lacking in moderate and small-sized UAVs. This will require not only research for an efficient airframe design, but for an efficiently integrated propulsion system as well.

1.3 UAV Control

Third, a computer control system or autopilot for this aircraft must be developed. Although, the hardware from current autopilots may be adapted for this research, new algorithms will be required for energy management, aerodynamic surface control, and buoyancy control. In particular, efficient path planning will be required for a vehicle based on PSB technology because of its likely susceptibility to wind. If a vehicle of near neutral buoyancy is developed it will be able to maneuver in a manner unlike most fixed-wing aircraft and may be ideal for urban environments with a properly programmed autopilot.

1.4 Energy Management

Fourth, efficient energy management techniques will be researched and designed into the UAV. The approach will be to adapt the current state-of-the art energy systems (batteries, solar cell, fuel cell, super capacitors, etc.). The UAV will be designed with the latest near-term advances in energy storage in mind and developed with efficient energy use algorithms that will enable long duration flight.

2. THE CASE FOR PRESSURIZED STRUCTURES

There are more than a few reasons to use pressurized structures for UAVs. The main benefit of the use of pressurized structures is to reduce the weight of the aircraft. The weight may be reduced by decreasing the mass of a comparable component and it may be reduced by using a lighter-than-air inflation medium. This in turn could lead to increased slow-speed maneuverability, VTOL and possibly hovering capability which is crucial for navigating urban environments. Another reason to use the pressurized structures is portability. A pressurized structure can be deflated for storage and occupy only a small fraction of its inflated volume. More advanced PSB technology may allow advanced features such as shape changing simply by selective inflation of aircraft components. It is also possible that PSB technology could reduce the cost of UAV construction.

These reasons are each worthy of examination, but taken separately, appear to give only an incremental improvement to UAV performance and fail to capture the possible benefits of a new paradigm in UAV design. In order to have an appreciation for the gained benefits, one needs to examine how UAVs are used today versus how they should be used in the future. As stated earlier, the focus of the UAV design is to perform missions critical to the Army. There are a number of missions which can be performed more efficiently with improved UAV performance. If a Soldier requires immediate UAV support, one option is to bring the UAV, and fly it into position moments before the reconnaissance is required. This is because the UAV will have flight duration of approximately 1.5 hours or less, and will likely produce enough noise to give away the element of surprise. This manner of operation requires multiple Soldiers' full attention to fly and recover the UAV during a mission.

The UAV flown is likely to be a fixed-wing aircraft. Fixed-wing aircraft currently are the most efficient form of commercial-off-the-shelf (COTS) UAV. They provide the best current compromise between endurance, speed, and payload. But the deficiencies of the current class of UAVs are well documented. Following are some of the issues

attributable to the fixed-wing design of the current class of UAVs.

During the height of UAV use in Iraq, collision avoidance was a tremendous problem. Fixed-wing aircraft required a fair amount of area to operate because they needed air flowing over the wings to maintain lift. UAV use was later managed using flight plans. However, the flight plans were required to be filed a minimum of 24 hours in advance for small UAVs (Grant 2006). The time period is greater for larger UAVs. This greatly hinders the ability to respond quickly to mission surveillance requirements.

The UAV noise issue has been touched upon. The problem is that even though small UAVs can perform their primary function of surveillance; they will be detected. Figure 1 shows the distances at which a small electric UAV may be detected by microphone at different altitudes. This data was collected during a UAV test to measure UAV signatures performed by the U.S. Army Aviation and Missile Research and Development Engineering Center (AMRDEC) in Huntsville, AL 2008 (ARL external communication J. Baeder 2008). A substantial amount of electro-magnetic-based signature tests were also performed. Some of the vehicles used in the signatures test were prepared and flown by U.S. Army Research Laboratory (ARL) personnel.

The data in Figure 1 was collected from a UAV with a propulsion system that used a brushless electric outrunner motor turning a two-bladed propeller, without a transmission. It is one of the quieter COTS systems available. The data demonstrates that these types of systems are easily detectable by noise from more than a kilometer away. Predictably, the noise was greatest at the propeller's fundamental harmonic which is also the motor's second fundamental harmonic. The noise at the motor's rotational frequency was relatively quiet when compared to the noise at the propeller's fundamental harmonic, indicating that the propeller is the greatest noise source. The acoustic signatures test actually employed an array of ground-based microphones. The data from Figure 1 is from just one microphone in the array. Even at night, it is possible to track a UAV by the noise its propulsion system emits. UAV operators have commonly practiced manually flying the aircraft, turning off the motor, and gliding it silently over its targeted surveillance area. This implies that an experienced operator is required to operate the aircraft in this manner while in the field.

Another issue with the current small fixed-wing aircraft is that because they must bank to turn, and they must be in constant motion, it is difficult to use camera information from them for targeting. Due to a lack of accuracy, geographic locations derived from camera information of small UAVs must be verified by at least one other source before it can be used for targeting. Targeting can be performed in larger platforms which are more stable and have the payload capacity to carry a stabilized gimbal for its camera.

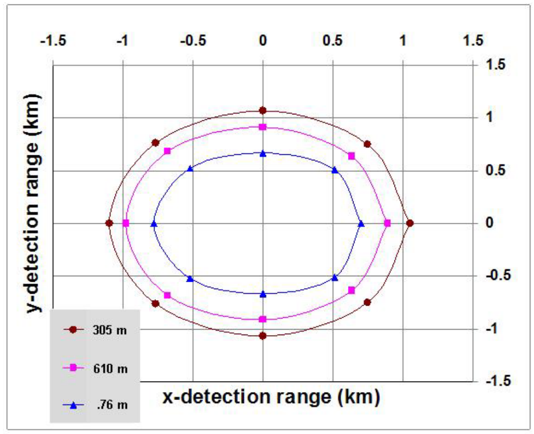


Fig 1. UAV detection from noise

Soldiers that operate UAVs in the field are still required to carry, assemble, and maintain a large amount of equipment. Although considered man-portable small UAVs require multiple rucksacks.

So how can PSB technology be used to address these issues? A more optimal solution for UAV use would be to fly the UAV into position well before the mission is to take place, and provide information as called upon by the Soldiers performing the mission. By increasing UAV endurance and range, the necessity for engaged Soldiers to carry, assemble, and launch UAVs in the field would be lessened. It is more likely that the UAVs could be deployed further away from engagement points. In this way, the only equipment a Soldier would need to carry would be a communication device to transmit directives to and receive information from the already deployed UAV. The extended duration afforded by the PSB technology can be used to build a persistent airborne sensor network that any Soldier could receive data from. This approach would also be useful in controlling UAV air traffic.

The current generation of fielded UAVs lack VTOL, and hovering capability. VTOL, hovering and/or slow precision maneuverability can be designed into PSB UAVs. This capability addresses

some of the issues of air traffic control by keeping UAVs in well-defined air traffic lanes. It also addresses issues with targeting because PSB aircraft designed to employ buoyancy can be inherently stable in an unpowered or low-power state. With hovering capability, only relatively inexpensive sensor stabilization platforms are needed for cameras. This will greatly enhance targeting capability for relatively cheap aircraft. The VTOL, hovering, and slow precision maneuverability will also be necessary for urban operations where UAVs will be counted upon for targeting and tracking in the future.

It will require a systems approach to combat the issue of UAV noise. The PSB technology can be used to reduce the weight and thus the power required to sustain flight. Reduced power requirements imply reduced amounts of noise generated from the motors and propellers. Also, the tactic currently used by Soldiers of turning off the UAV motor when approaching an area of interest may be useful for future PSB UAVs. PSB UAVs may be designed with higher glide ratios than current UAVs. They may be able to increase their glide ratios through selective inflation of lift surfaces. However, the main benefit will be that the PSB UAV will be programmed to perform this operation and the Soldier will not be required to actively monitor or control the UAV in this aspect of the operation. Most importantly, a PSB aircraft used for surveillance may be designed for quiet hovering. The system should be designed to be energy efficient in hover mode so that little propulsion power is required to sustain flight. A PSB aircraft can employ buoyancy to keep this energy to a minimum.

In order for PSB UAVs to perform in the prescribed manner, they must have increased flight duration and stealth. For pressurized structures-based vehicles, the increased duration can be provided by the decreased weight afforded by the inflatable structures and buoyancy provided by the lighter-than-air inflating medium. Stealth would be provided by the reduced propulsion power required by the lighter weight airframe and the proportionately reduced noise. As stated earlier, some improvements in propulsion technology would be required to further reduce noise. Stealth can also be achieved by the flight pattern of the UAV. The UAV can be designed to fly at altitudes where it is difficult to see and hear. Since a pressurized vehicle that takes advantage of buoyancy is likely to be larger than a UAV constructed with conventional means, it may need to fly higher or require a form of camouflage to achieve visual stealth.

3. PRESSURIZED STRUCTURE COMPONENT TECHNOLOGIES

Pressurized structure is a generalized term that describes an inflatable UAV component. There are many examples of pressurized structures used in aircraft. The blimp is the most obvious example. There are examples of inflatable fixed-wing UAVs. Hybrid concepts have been proposed in which a blimp-like, helium-filled envelope is attached to a frame with helicopter rotors to perform heavy lift projects. Below are PSB technology concepts that are under consideration for UAV construction.

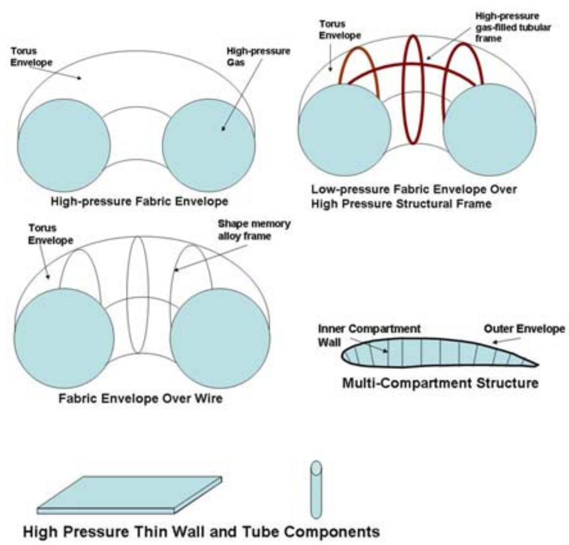


Fig. 2. Various pressurized structure concepts

Different types of UAV designs will require different types of pressurized structure solutions. For UAVs designed for moderate scale and cost, the high-pressure fabric envelope and fabric envelope over wire seem to be the most promising near-term solutions. The use of a high pressure gas structural frame seems to be a promising means to build large light weight UAVs. Pressurized structures may be used to build conventional types of airframes. Instead of materials such as foam and carbon fiber, an inflatable structure is used. For example, ILC Dover has produced UAVs with inflatable wings. For their wing designs, the benefits of using the inflatable wings were storage and the ability to change shape with variable camber (Cadogan et al. 2004).

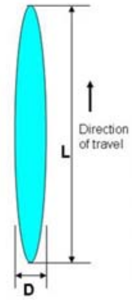
Although there have been previous attempts and concepts using pressurized structures, there have not been many outdoor small to medium UAV designs. Aerostats are the most popular form of pressurized

structure for military use. Their most likely mission is persistent surveillance. One of the initial goals of this research is to develop inexpensive moderately sized UAVs with critical dimensions 10 ft (3 m) or lower. Until fairly recently, it was difficult to realize the reduced weight benefits offered by pressurized structures for vehicles at this scale. One of the key reasons for that is materials technology. Today, one of the best current COTS solutions for durable envelope material is ripstop nylon infused with or bonded to a helium barrier which is usually urethane based. Depending upon factors such as inflation pressure, cruise altitude, structural requirements, etc., ripstop nylon material weighs approximately 2.2-5 oz/yd^2 (74.6-169.55 g/m^2). This contrasts with some of the newer material candidates for envelopes such as cuben fiber that weighs approximately .7-.85 oz/yd^2 (23.7-28.8 g/m^2). To appreciate the potential weight savings compare the weight of an envelope made from nylon versus one composed of cuben fiber. For a UAV with critical dimensions of 10 ft, one can expect to use on the order of 100 ft^2 (9.3 m^2) of envelope material. This means that the weight savings of cuben fiber for this size of vehicle would be approximately 15- 46 oz (425-1304 g). Because cuben fiber has strength comparable to Kevlar, it may have a number of applications within a pressurized structure.

4. UAV DESIGN

There are significant tradeoffs required to make this approach work. One of the more important tradeoffs in designing lighter-than-air vehicles is buoyancy versus drag. To increase buoyancy, one must increase volume. For a given length, as one increases the volume of an envelope, one must increase the cross-sectional area and thus the drag. The drag determines key characteristics of the mission profile, vehicle speed, and power requirements. By looking at an analytical analysis of a common shape used for lighter-than-air vehicles, a body-of-revolution ellipsoid, one can readily see the relationship between volume, drag, and power to sustain flight. In addition, the relationship of power to noise gives an indication of the percentage of noise that can be reduced by using lighter pressurized structures. Following is a table that is indicative of characteristic values used in the design of a lighter-than-air envelope. The table shows computed values for a typical body-of-revolution ellipsoid with a characteristic length of 8.2 ft (2.5 m) within the current design specification.

Table 1. Computational Data for Ellipsoid Envelopes



L/D, L=8.2ft L=2.5m	Vol ft^3 (m^3)	Cd (in direction of travel)	Lift lb (N)	Power hp
2	65.0 (2.05)	0.479	4.713 (20.97)	0.698
3	31.8 (0.90)	0.381	2.078 (9.24)	0.244
4	18.0 (0.51)	0.316	1.178 (5.24)	0.116
5	11.5 (0.33)	0.284	0.754 (3.35)	0.066
6	8.12 (0.23)	0.281	0.532 (2.37)	0.046

Within the table are computed values for envelopes of the same length (L), but varying diameters (D). Also included are values for computed volume, drag coefficient, lift or buoyancy if the envelopes were filled with helium, and the power that is required to move them through the air at 20 mph (32.2 kph) based on analytic solutions. The table was prepared to illustrate the tradeoffs applicable to a number of pressurized structure designs. The important items to note are that the drag coefficient for forward flight changes moderately. However, the power to maintain a steady velocity of 20 mph changes quite a bit between L/D of 3 and 4. Another point to note is that the lift from buoyancy suffers for high L/D. However, it can be partially recovered by the aerodynamic lift generated when the body is flown at small positive angles of attack (Costello 1998). Table 1 shows the compromises that must be made to take advantage of buoyancy, while still maintaining reasonable speeds. The table above indicates that an L/D greater than 5 would provide the best aerodynamics for power efficiency at 20 mph flight speeds. A patent was recently given in 2007 for airships with L/D greater than nine that exploit low drag. However, the lift from buoyancy is diminished for higher L/D. One compromise that may work for these types of envelopes is to use multiple envelopes.

Pressurized structures could be used in common aircraft design or be used in yet to be imagined designs. For brevity, one concept of a pressurized structures-based research vehicle will be discussed. Following is a concept that tries to exploit the benefits of the simple high L/D envelope. It is a concept for a research aircraft that may be used to test a number of the ideas previously discussed.

The aircraft is an envelope on frame design. This means that there is a simple light weight reconfigurable frame most likely constructed with a carbon fiber or plastic spine with wings, elevator, and rudder that supports one or multiple envelopes. In the future, the spine may be replaced with a high-

pressure structure. For this first research aircraft, it was determined that the frame should be capable of sustaining flight in the event of envelope failure. Models of the frame with and without envelopes were created and flown in the X-Plane flight simulator to ensure it was stable in forward flight. X-Plane is a well-established flight simulator and an FAA-certified version is available (Meyer 2007). These models can be seen in Figures 3 and 4. These particular models have wingspans of 8 ft (2.44 m). Each envelope has a length of 10 ft (3.05 m) and a diameter of 1.5 ft (0.46 m).

This design is quite flexible in the manner it can be configured. It can be scaled up or down in dimensions and have very similar flight characteristics. One can imagine a number of variations that can be explored with this vehicle. A number of different envelope shapes and construction types can be tested. The number of envelopes and propulsion devices may be varied as well. Different types of propulsion systems may be adapted and attached to the frame or envelopes in different locations using different techniques.

The aircraft is currently modeled with variable pitch propellers on motor nacelles that can be rotated forward and aft. Unfortunately, X-Plane does not allow the nacelles to vector the thrust left or right. Roll control may still be performed by varying propeller pitch or motor speed between the left and right propulsion pods. Currently, the propeller pitch and motor speeds for the left and right motors are identical. With only two propellers mounted near the center of gravity, the aircraft is only marginally stable while hovering and does not hover well with the nacelles rotated upward and normal to the wind. It does exhibit very good slow forward speed flying qualities in simulation.

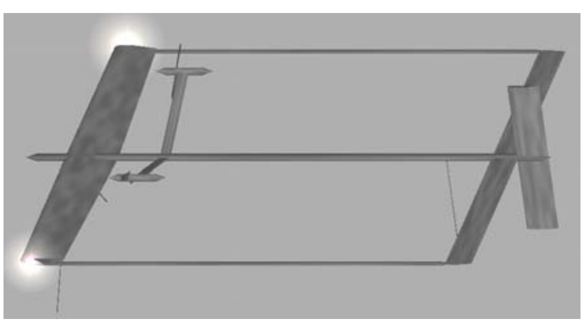


Fig. 3. Airframe base for envelopes

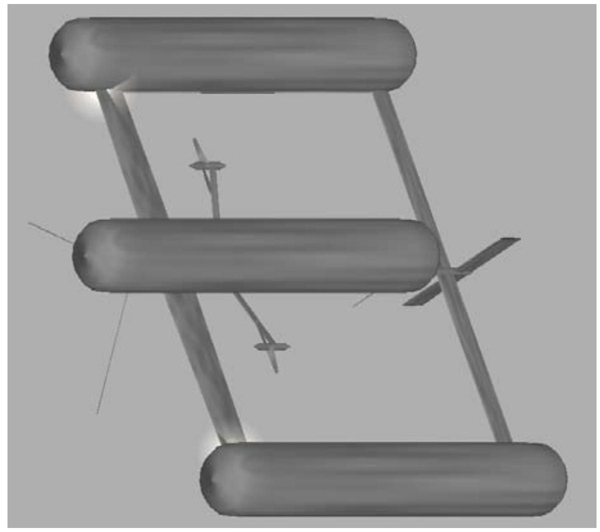


Fig. 4. Airframe with envelopes

5. UAV CONTROL

Some of the controls necessary for a PSB UAV to have the increased capabilities to carry out long endurance missions in a manner that will impact the Army in a meaningful way have been discussed. The UAV should be capable of VTOL flight. The UAV should be able to fly slowly and precisely in a urban environment. In order to have the endurance to fly for extended periods of time, there must be some controls for energy management. Although an effort will be made to make the vehicle quiet through re-engineering of the propulsion system, it is still unlikely in the near term that a sufficiently quiet propulsion system will be developed that can allow a UAV to silently approach a target without detection. There must be higher level path-planning control software that takes stealth into account. One way to do this would be to emulate the technique already used by Soldiers which takes the wind into account. This is not out of the question for an autopilot. An autopilot developed with ARL funding by Dr. N. Sleger has been programmed previously for unpowered parafoil payload deployment (fig. 5). In such a use, the wind is taken into account to enable the payload to be steered to a predetermined coordinate. This technique could be modified to allow a UAV to fly upwind of a target coordinate then glide silently over it to perform its mission (Slegers et al. 2006). PSB UAVs could be designed with glide slopes specifically for this type of operation. If the vehicle is partially buoyant, it would further enhance this capability.

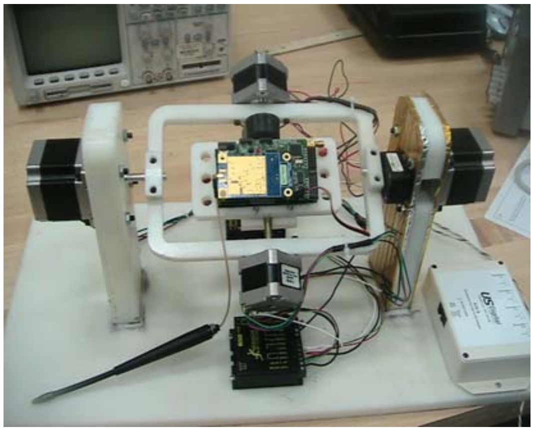


Fig. 5. Autopilot on hardware-in-the-loop simulation gimbal

The initial tests for the propulsion controls have been made with the ARL-funded autopilot. A test stand was built with two propulsion pods mounted in a similar manner to the UAV model developed for X-Plane. The autopilot was mounted on the test stand such that it shared the angular orientation of the motors. Each motor drove a variable pitch propeller. The autopilot was able to control both the motor speed and propeller pitch to control the roll angle of the test stand using a simple proportional-derivative controller. Figure 6 shows the test stand and a graph showing the propulsion system returning the roll to zero after several impulses have been imparted to the test stand (ARL internal communication Janas, Edge, Collins July 2008). Although the variable pitch propellers allowed for quick precise control of attitude, at some motor speeds it only generated fifty percent of the thrust of a similar diameter fixed-pitch propeller. The COTS variable-pitch propeller was designed for acrobatic performance, and not efficiency. The tests were successful, but it showed that in order to maximize efficiency, custom designed propellers or ducted fans would be needed. It is anticipated that for the precision maneuvering that will be attempted a more complex control algorithm such as model-predictive control will be used. This type of control has also been used previously with the autopilot.

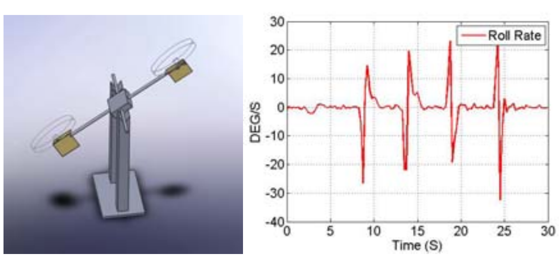


Fig. 6. Propulsion test stand and response to impulse

In addition, the autopilot, test gimbal, and X-Plane have been used cooperatively to form a hardware-in-the-loop simulator. This can be used to test algorithms on the autopilot with models built in the X-Plane simulator.

.

6. ENERGY MANAGEMENT

In order to perform missions that require extended flight time, energy management is a necessity. Since weight control is a primary concern, considerations are being made to not only use and store energy efficiently but generate it. It is anticipated that the propulsion system will most likely be electrically powered. This is because electric motors produce less noise than internal combustion motors, the electric motors can be turned on and off at will, and the power supply can be replenished without landing by recharging the batteries. The two most obvious ways for a UAV to generate power to recharge batteries is to use solar cells or the wind. Of course, the solar cells can only be used when there is sufficient light. The wind may be used as long the UAV has altitude and velocity. The procedure would be to glide and use the propellers as windmills to generate electricity. Figure 7 is a conceptual drawing of a future energy management system.

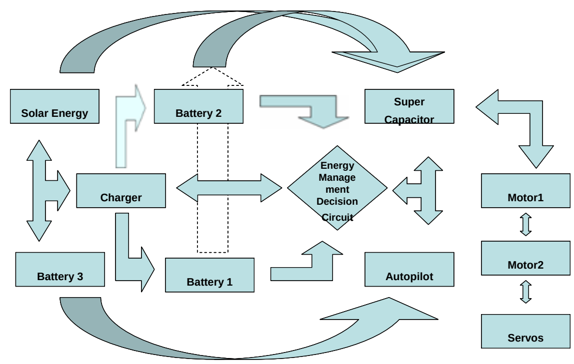


Fig. 7. Proposed UAV energy management system

Currently, much of the UAV COTS component sources are based within the radio-control aircraft industry. The lithium-polymer batteries and brushless motors that have revolutionized electric-powered aircraft are not ideally suited to in-flight recharging. During tests of COTS components, it was determined that some of the fail-safe measures programmed into the components to ensure that batteries are charged safely, make it difficult to run a charging system consistently. Thus, custom circuitry will need to be developed. One of the major issues with the tests was that it was difficult to keep power running consistently to all components. For example,

if using solar cells to supply power, one cannot expect constant current and voltage while in flight. The other issue is that there would be great losses in efficiency when power was generated but could not be directly input into the batteries because of the very specific charge profile required. Thus, power would be wasted (ARL internal communication Ross and Edge July 2008). One item that may make recharging easier is the supercapacitor. Supercapacitors allow substantial amounts of electricity to be stored and drawn without damaging circuits. In comparison, lithium-based batteries may require very specific charge and discharge profiles. Supercapacitors are lighter than batteries and may be built into structural components. This research is currently underway at ARL (Wetzel et al. 2006). Looking at Figure 6, one notices that there are multiple batteries listed. This is a concession to the possibility that the battery formulation may require a rest period between use and charging. It also provides a convenient way to have an emergency power supply.

The X-Plane model is designed to be flexible and reconfigurable to test different energy management concepts for pressurized structure aircraft such as solar power and wind energy recovery. For example, the envelopes provide sufficient area to mount enough solar cells to power the propulsion system. Solar cells from PowerFilm Inc. were tested for compatibility with potential power components. It was not anticipated that the solar cells would generate a lot of heat. Under full sunlight, the solar cells would reach over 140^{o} F. This will force special design considerations for the envelopes. A method may be found to use the heat to aid vehicle efficiency. The PowerFilm solar cells provide 3.04 W/ft^2. (32.72 W/m^2) If 10 ft^2 (0.929 m^2) of surface for solar cells were placed on each envelope, then 304 W of power could be generated. PowerFilm offers a version of its solar cells for radio-control aircraft. They weigh approximately 1.16 oz/ft^2 (35.53 g/m^2). Therefore the total weight of the solar cells would be 34.8 oz (986.58 g). The solar cells produce significant power, but they also weigh quite a bit. More solar cells could be added to the wings if more power is required. However, data from X-Plane simulations indicate that for the envelope on frame design, 260 W of power are required for sustained speeds of 25mph (40.2 kph). Depending upon the mission, this design should be capable of long endurance flights during daylight hours.

CONCLUSIONS

This paper discusses the initial findings in the use of pressurized structures for UAVs. Current UAV design and technology has limitations that hinder the advancement of UAV utilization in the Armed Forces. Although it cannot solve all of the issues experienced by the current generation of UAVs, pressurized structures appear to provide a technology around which most of the solutions can be based. By offering lighter weight, VTOL, slow flying, hovering, reduced noise, and increased endurance capabilities, PSB UAVs may provide an avenue to greater mission capability for future UAVs.

ACKNOWLEDGMENTS

The authors would like to thank Janet Baeder (AMRDEC) for providing the UAV signature data.

REFERENCES

Cadogan, D., Smith, T., Uhelsky, F. MacKusick, M., 2004: Morphing Inflatable Wing Development for Compact Package Unmanned Aerial Vehicles, AIAA-2004-1807, 45th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Palm Springs, CA, April 2004.

Costello, M., 1998: Extended Range of a Gun Launched Smart Projectile Using Canards, 9th Annual Gun Dynamics Symposium, Mc Lean, VA, November 1998.

Grant, G., 2006: U.S. Army May Scale Back UAV Plans, C4ISR Journal, June 2006.

Konstantinov, L., 2003: The Basics of Gas and Heat Airship Theory, Montgolfier, ed. Aeroplast , Kyiv, Ukraine, 2003.

Meyer, A., 2007: X-Plane Manual. http://x-plane.com/contact.html , August 2007.

Nickol C., Guynn, M., Kohout, L., Ozoroski, T., 2007: High Altitude Long Endurance UAV Analysis of Alternatives and Technology Requirements Development, NASA/TP-2007-214861, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA , March 2007.

Slegers N., Kyle, J., Costello, M., 2006: Nonlinear Model Predictive Control Technique for Unmanned Air Vehicles, *Journal of Guidance Control and Dynamics*, 0731-5090, vol. 25, no. 5 (1179-1188), 2006.

Wetzel, E.D., O'Brien, D.J., Snyder, J.F., Carter, R.H., and South, J.T., 2006: Multifunctional Structural Power and Energy Composites for U.S. Army Applications, NATO-RTO Applied Vehicle Technology Panel Specialist Meeting on Multifunctional Structures and Integration of Antennas and Sensors. Vilnius, Lithuania. 2-5 October 2006.